Chapter 47

CURRENT ANESTHESIA EQUIPMENT

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INTRODUCTION

Military medical equipment technology has advanced significantly over time; however, compromises may still be required, especially when forward surgery is planned. Compact, light, and highly portable medical equipment is ideal for delivering anesthesia in Role 2 medical treatment facilities (MTFs) and for entry operations. This chapter will describe the range of general anesthesia equipment required at Role 2 and Role 3 MTFs to provide modern anesthesia.

DRAW-OVER SYSTEMS

Draw-over anesthesia systems have been part of anesthesia practice since its inception. The key components for any draw-over system are a one-way patient valve and a vaporizer that has a low resistance to breathing. Both UK and US forces have relied on draw-over anesthetic equipment in field medical situations. US forces are increasingly using compact conventional anesthesia machines, and at Role 3 facilities, conventional anesthesia machines have largely replaced draw-over systems. In more recent systems, a mechanical ventilator is usually added along with a means of removing anesthetic gases from the operating room. There are a number of examples of commonly accepted requirements for portable anesthetic apparatus in austere environments (Exhibit 47-1).[1]

The Triservice Anaesthetic Apparatus

The Triservice Anaesthetic Apparatus (TSAA) was developed by Brigadier Ivan Houghton and first described in 1981.[2] It is based on the revised version of the Oxford Miniature Vaporiser (Figure 47-1), the OMV50 (Penlon Ltd, Abingdon, UK). However, the OMV50 has recently ceased production, and the UK Defence Medical Services (DMS) is investigating a replacement for the TSAA.

Revisions from the original OMV50 included an increase in agent quantity to 50 mL and the addition of three “feet” to increase stability. The vaporizer is compact, lightweight, simple to use, and compatible with many modern volatile agents. Although it is not temperature compensated, antifreeze in the base makes it thermally buffered.

Although key components of the TSAA have remained the same, some changes since its inception have been described in a number of articles.[1,3] The one-way patient valve and a self-inflating bag (SIB) come from the Laerdal Resuscitator (Laerdal Medical Ltd, Orpington, UK). For general anesthesia in the spontaneous breathing patient, the one-way patient valve is connected to the SIB by a length of corrugated

EXHIBIT 47-1

ANESTHETIC SYSTEM REQUIREMENTS FOR AUSTERE ENVIRONMENTS

Anesthetic systems in austere environments must be:

- minimally reliant on compressed gases and electrical supplies
- robust
- compact and portable
- simple to operate
- able to withstand climatic extremes
- easily maintained and serviced
- economical
- compatible with various volatile agents
- versatile with regard to patient age/size

Figure 47-1. Oxford Miniature Vaporiser.
Product image used with permission from Penlon Ltd, Abingdon, United Kingdom.

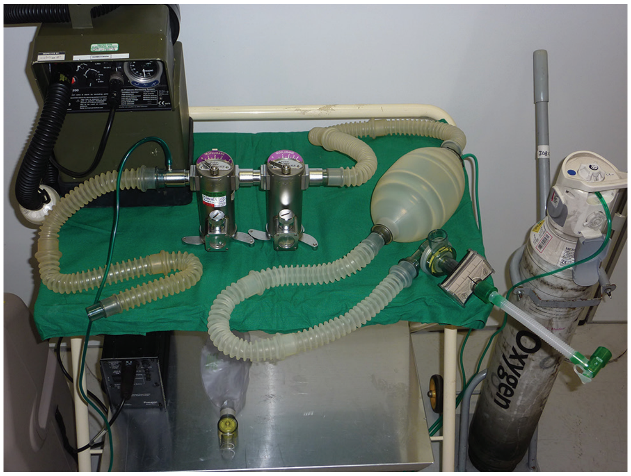

Figure 47-2. Triservice anesthetic apparatus, configured for spontaneous respiration.
Product image used with permission from Smiths Medical, Ashford, United Kingdom.

rubber tubing; a further length of tubing connects the SIB to the OMV50 (there are usually two vaporizers connected in the series because of the small volume of volatile agent each contains). Upstream of the second OMV50 is a Sanders injector (or T-piece), which is used to deliver supplementary oxygen. A further length of corrugated tubing acts as an oxygen reservoir (Figure 47-2).

It should be noted at this stage that all the connectors, from the one-way patient valve through the SIB and the vaporizers, are the old cage-mount standard (23.1 mm). The patient attachment to the one-way patient valve has a conventional International Organization for Standardization (ISO) 22-mm fitting. A ported shroud is usually fitted to the one-way valve to scavenge anesthetic gases, and it is also possible to attach a positive end-expiratory pressure valve at this point. The current UK approach to scavenging, in the absence of an active system, is to use a Cardiff Aldasorber (Shirley Aldred & Co Ltd, Derbyshire, UK). Unlike a conventional anesthetic machine or circuit, there is no bag to provide an indication of ventilation during spontaneous breathing. A modification of the circuit did help in this regard,[4] but a recent change in the SIB design made this modification impossible.

The apparatus may also be modified (Figure 47-3) for pediatric anesthesia.[3,5] A number of volatile agents

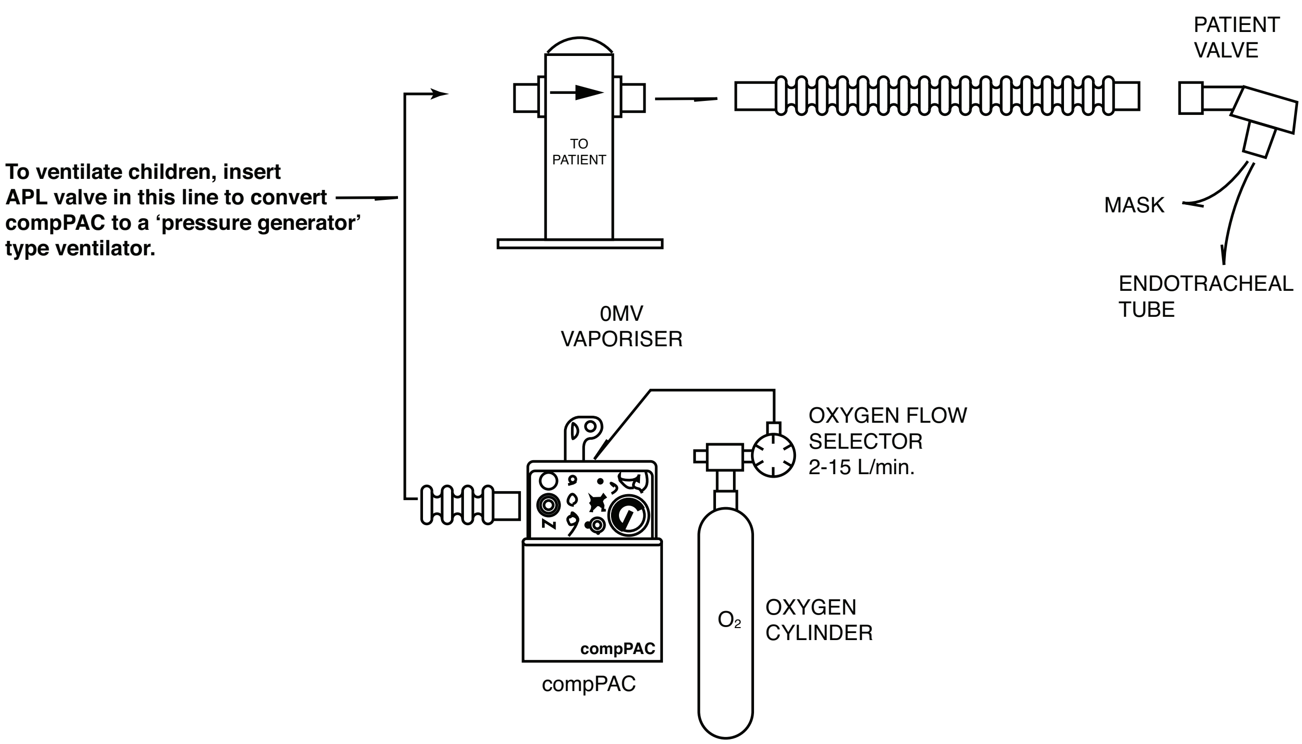

Figure 47-3. Triservice anesthetic apparatus, configured for pediatric anesthesia.
APL: adjustable pressure limit; OMV: Oxford Miniature Vaporiser
Product image used with permission from Smiths Medical, Ashford, United Kingdom.

Figure 47-4. CompPAC 200 ventilator and power supply. Product image used with permission from Smiths Medical, Ashford, United Kingdom.

may be used, including sevoflurane; however, even with two vaporizers in series, it is difficult to perform an inhalation induction with sevoflurane using the TSAA.

The CompPAC 200 ventilator[6] (Smiths Medical, Ashford, UK) is currently used with the TSAA to provide mechanical ventilation during general anesthesia (Figures 47-4 and 47-5). The CompPAC 200 is a time-cycled, pressure-preset flow generator. The driving gas is produced by an internal air compressor and stored in an internal cylinder, so it remains at the same concentration as room air. The inspired oxygen concentration can be increased by feeding oxygen (maximum 4 L/min) into the rear of the ventilator or by connecting high-pressure oxygen using the supplied Schrader cable to the connector on the front of the ventilator (in this situation the "air mix/no air mix" control is operational). During anesthesia, it is normal to feed the oxygen supply from the concentrator into the T-piece and not use the connection at the rear of the ventilator. The ventilator is versatile; it can be driven from a range of electrical supplies as well as a source of high-pressure oxygen.

A potentially significant patient safety issue may occur when using the ventilator with the TSAA. The original design SIB *must* be removed from the circuit before turning on the CompPAC 200 to ventilate the patient; failing to do so has resulted in separate cases of failure to ventilate (merely ventilating the SIB) and "breath stacking," in which the patient does not exhale during the expiratory phase and continues to receive gas during inspiration. The newer design SIB is located where the ventilator connects to the circuit, making it easier to remember to remove it.

Another potential patient safety issue is the tendency for the circuit to come apart at one of the numerous connections. Users must be aware of this and strive to firmly seat all connections. Because of the unique nature of the TSAA, military anesthetists train to use it in a high-fidelity simulation course.[7]

Figure 47-5. Triservice anesthetic apparatus, configured for mechanical ventilation.
Product image used with permission from Smiths Medical, Ashford, United Kingdom.

Figure 47-6. Ohmeda Portable Anesthesia Compact vaporizer.
Product image used with permission from General Electric Healthcare, Chalfont St Giles, United Kingdom.

US Draw-Over System

The US draw-over system is based on the Ohmeda Portable Anesthesia Compact (PAC [General Electric Healthcare, Chalfont St Giles, UK]) vaporizer (Figure 47-6). Basic components include an Ambu-E valve (Ambu A/S, Ballerup, Denmark) vaporizer, tubing, and SIB (Figure 47-7). The dial located on the top of the vaporizer can be unscrewed and turned over for use with other anesthetic agents. For example, the settings for sevoflurane are on the reverse of the dial, and a chart stamped on the unit describes settings for other volatile anesthetics. However, the Ohmeda PAC has not been manufactured for some years and alternatives are being investigated.[8]

Although the sevoflurane output has been described,[9] at present the only anesthetic used with this system is isoflurane. Like the OMV50, the vaporizer tends to consume isoflurane (and other volatile agents) more quickly than a conventional anesthesia machine, so it is important to monitor the level of agent remaining in the reservoir. Vapor consumption depends on flow rate as well as the output concentration selected on the dial. Vapor consumption can be calculated using the following formula: $3 \times \%F$, where F is the flow in liters per minute, % is the vapor output setting on the dial, and 1 mL of liquid agent is equivalent to 200 mL of vapor.

The vaporizer unit should be used in a temperature-controlled environment above 12ºC to 15ºC (54ºF–59ºF) and below 35ºC (95ºF). At temperatures above 35ºC (95ºF), potentially hazardous concentrations of agent may be delivered. Experience in Afghanistan when temperatures exceeded 100ºF showed that the dial needed to be set lower than usual to avoid high concentrations of volatile agent. Because the circuit does not lend itself to the attachment of a scavenging system, it should be used in a well-ventilated room.

Figure 47-7. Ohmeda Portable Anesthesia Compact circuit. Product image used with permission from General Electric Healthcare, Chalfont St Giles, United Kingdom.

The Ohmeda PAC can be used in series with an Eagle Univent Ventilator (Progressive Medical International, Vista, CA). It may be used in either a pull-through[10] or a push-through[11] method, depending on where the ventilator is placed in relation to the vaporizer.

Using the Draw-Over With the Univent

This method places the ventilator between the vaporizer and the patient. The ventilator "pulls" the anesthetic gas from the vaporizer, so it is effectively still a draw-over device. It can be difficult to determine the amount of anesthetic gas entering the ventilator. Supplemental oxygen is normally provided via the vaporizer, but caution is advised when using supplemental oxygen via the ventilator. Volatile anesthetic gases enter through the side port into the internal air compressor; by selecting air-oxygen values greater than 21% on the air/oxygen mixer dial, relatively less anesthetic gas will enter the ventilator. At an inspired oxygen concentration of 100%, virtually no anesthetic gas will be provided by the ventilator.

Set up the Univent as follows:

1. Attach the 36-inch, clear plastic hose from the Univent circuit package between the vaporizer output connector and the ventilator's internal air-compressor side port.
2. Attach an 84-inch breathing circuit from the top of the ventilator gas output port to the patient.
3. Connect the clear circuit exhalation valve and green transducer to the circuit and the ventilator.
4. Shorten the Univent connector hose and circuit by cutting the cuffs that are located every 6 inches along the tubing.
5. If a problem occurs and the patient needs to be manually ventilated, disconnect the Univent tubing and attach the vaporizer inhalation limb and breathing bag.

Push-Through Method

The push-through method places the vaporizer between the patient and the ventilator, allowing the ventilator to "push" gas over the vaporizer to the patient. The push-through method can be performed using the following steps:

1. Using the long black tubing of the Ohmeda PAC, connect one end to the "patient gas out" connector on top of the Univent and the other end to the air inlet connector on the Ohmeda vaporizer.

2. Attach the Univent breathing circuit from the Ohmeda vaporizer output port to the patient.
3. Connect the clear circuit exhalation valve and green transducer to the circuit and the ventilator. The Univent ventilator has a hose connector on top of the unit for adding pressurized oxygen to the system. For this feature to work, oxygen pressure must be greater than 40 psi. The air/oxygen mixer dial can then be set for a fraction of inspired oxygen (FiO_2) of 0.21 to 1.00. Low-pressure oxygen may be added to the ventilator via the side port internal compressor. This is done by attaching the clear connector hose from the circuit package to the internal compressor side port of the ventilator. An oxygen tube can then be passed into the hose to provide a reservoir of oxygen. The FiO_2 delivered is a function of both the oxygen flow rate and the length of reservoir hose used, and can be measured with an oxygen sensor (Table 47-1).

CONVENTIONAL GENERAL ANESTHESIA MACHINES

Both UK and US forces now use conventional anesthesia machines. This is becoming a core item for Role 2E (enhanced) and Role 3 MTFs for the United Kingdom; US forces have relied on conventional machines for both Role 2 and Role 3 MTFs for a number of years.

Dräger Fabius Tiro M

UK and US forces have worked with Dräger to develop a militarized version of the Fabius Tiro machine (Dräger AG & Co, Lübeck, Germany). The UK DMS recognized that for enduring operations in a Role 3 facility, a conventional anesthesia machine was more appropriate than a draw-over system, and after reviewing relevant systems available at the time, chose the Fabius Tiro (Table 47-2). The variant adopted was a two-gas machine (oxygen and air) with a conventional three-drawer trolley (Figure 47-8). There are separate control knobs for the gases with light-emitting diode displays for gas flow; a single rotameter indicates total gas flow. The circle system can be fitted with a disposable absorber canister, or a different canister can be fitted to use loose absorbent. Low-volume pediatric tubing is also available. Sevoflurane is the volatile agent used.

The ventilator is an electrically driven (gas-efficient), modern design. There are four modes of ventilation available: (1) volume, (2) pressure, (3) pressure sup-

TABLE 47-1

EXPECTED FIO_2 WITH VARYING OXYGEN FLOW AND RESERVOIR LENGTH

Oxygen Flow (L/min)	Reservoir Hose Length (ft)	Approximate FiO_2 Delivered
2	3	0.45
4	3	0.55
4	6	0.65
6	6	0.85

FiO_2: fraction of inspired oxygen

TABLE 47-2

SPECIFICATIONS FOR THE DRÄGER FABIUS TIRO M*

Characteristic	Values
Tidal volume (VC):	20–1,400 mL (20–1,100 mL, SIMV/PS)
Rate	4–60 breaths/min
PEEP/CPAP	0–20 cmH_2O
Inspiratory flow	10–100 L/min
I:E ratio	4:1 to 1:4
Inspiratory pause	0–50%
SIMV inspiratory time	0.3–4 sec
Inspiratory pressure	(PEEP + 5) to 65 cmH_2O
Inspiratory flow	10–75 L/min (VC, PC), 10–85 L/min (PS)
PS level	PEEP +3 to 20 cmH_2O
Trigger	2–15 L/min
Size, set up on container (H × W × D)	47.2" × 49.8" × 31.9"
Weight, set-up on container	91 kg (198 lb)
Power supply	100–240 VAC 50–60 Hz

*Manufactured by Dräger AG, Lübeck, Germany.
CPAP: continuous positive airway pressure
I:E: inspiration to expiration
PC: pressure control
PEEP: positive end expiratory pressure
PS: pressure support
SIMV: synchronized intermittent mechanical ventilation
VAC: volts alternating current
VC: volume control

Figure 47-8. Fabius Tiro: UK version.
Product image used with permission from Dräger AG, Lübeck, Germany.

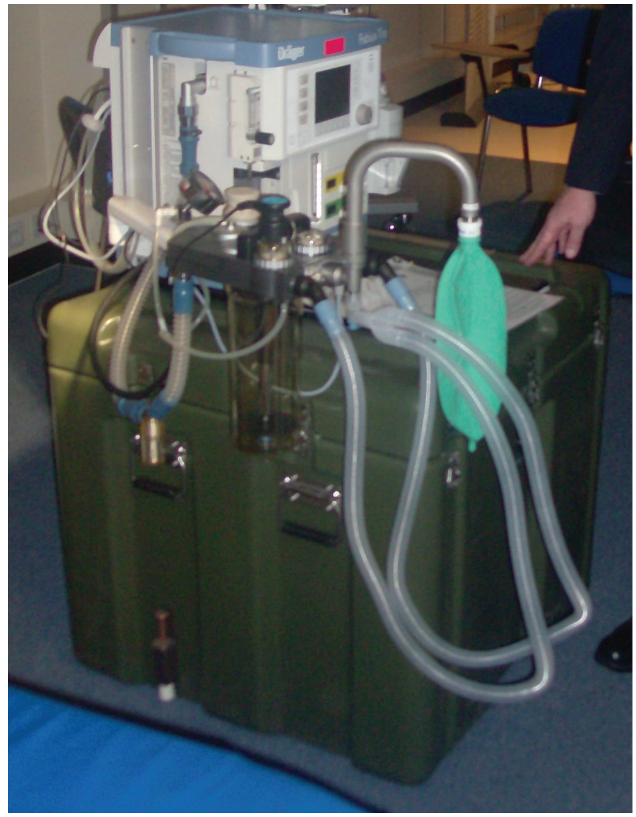

Figure 47-9. Fabius Tiro M: US version.
Product image used with permission from Dräger AG, Lübeck, Germany.

port, and (4) synchronized intermittent mandatory ventilation with pressure support (SIMV/PS). The first two are standard, but the latter have been specified by the UK DMS. The ventilator automatically compensates for the compliance of the tubing to maintain a set tidal volume.

The machine accepts a range of input voltages and has a battery backup, which is quoted to last 45 minutes. Oxygen and air supply requirements are the same as for any modern machine in terms of pipeline and cylinder requirements. In the absence of a high-pressure pipeline supply, the machine works well when connected to a ZX-size cylinder (3,040 L oxygen) instead.

Although US medical services use a similar Fabius Tiro at larger Role 3 facilities, they have worked with Dräger to design a more compact version for Role 2 MTFs in which the three-drawer trolley has been removed and the main working section of the machine is packed in a transport container (Pelican-Hardigg, Torrance, California). This container becomes the working platform for the machine on deployment, which creates a smaller overall package, although the footprint is larger (Figure 47-9). Another US development is a portable oxygen generator system (POGS; On Site Gas Systems Inc, Newington, CT), which can supply a single machine with all of its gas requirements. The POGS-10 only supplies up to 11 L/min of oxygen, so the oxygen flush will not work in the conventional manner because the machine input will always be limited by the POGS-10 output.

Dräger Narkomed M

The Dräger Narkomed M (Dräger AG & Co, Lübeck, Germany) is used at most Role 2 forward operating bases. It is a compact, lightweight, continuous-flow anesthesia system (Figure 47-10). Narkomed M machines are equipped with airway monitoring capabilities and a pneumatically driven ventilator to deliver gases and anesthetic vapor to adult and pediatric patients. The Narkomed M is easily transported in two protective containers.

The machine can deliver oxygen, air, and nitrous oxide, although nitrous oxide does not tend to be used in theater MTFs. There is a single vaporizer, and

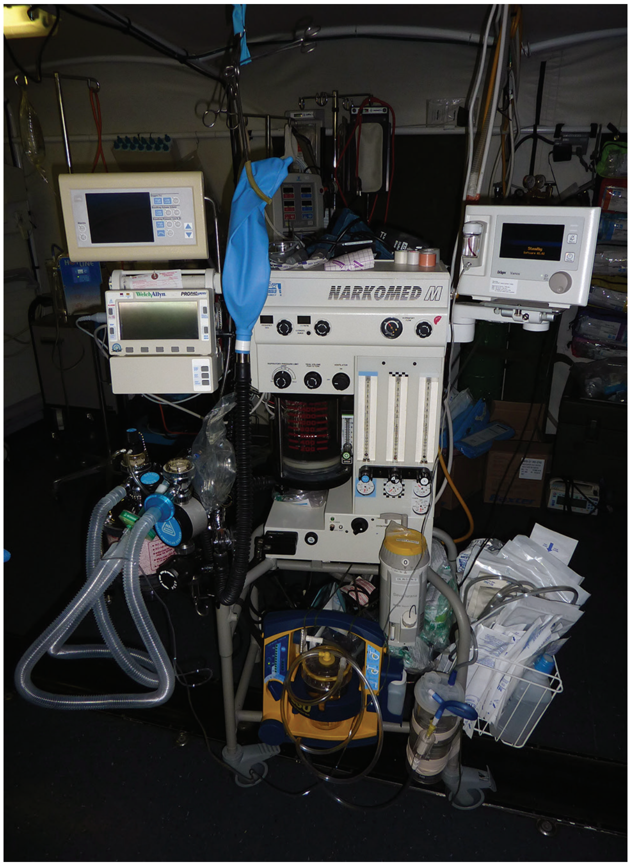

Figure 47-10. Dräger Narkomed M with Vamos and Propaq monitors.
Dräger Narkomed M and Vamos images used with permission from Dräger AG, Lübeck, Germany. Propaq image used with permission from Welch Allyn, Beaverton, Oregon (shown is the Encore 200 model, which has been discontinued and replaced by the Zoll Propaq M and Propaq MD).

pipeline connectors and the oxygen cylinder yoke are located on the back of the machine. However, there is no provision for air cylinders. Individual flow meters for each gas are located above their corresponding flow-control valve. A float indicator is in each flow tube and should be read at the center to determine gas flow rate. A pneumatic interlock system, the oxygen ratio controller, allows independent control of oxygen and nitrous oxide flows and will maintain a fresh gas oxygen concentration of 25% (± 4%) to prevent delivery of a hypoxic mixture. In the event of a loss of oxygen pressure, the Narkomed M is equipped with a pneumatically operated oxygen-failure protection device (Table 47-3).

Isoflurane and sevoflurane are available to US anesthesiologists and are delivered from a Dräger Vapor 2000 vaporizer. The absorber system accommodates sensors to monitor oxygen concentration, tidal volume, respiratory minute volume, and respiratory frequency. The desired mode of operation is selected with the manual/automatic selector valve. Absorbent can be either soda lime or barium hydroxide. A pressure gauge is located on the absorber to monitor breathing-circuit pressure (Figure 47-11).

TABLE 47-3

SPECIFICATIONS FOR THE DRÄGER NARKOMED M*

Characteristic	Values
Tidal volume	50–1,500 mL
Rate	1–99 breaths/minute
PEEP/CPAP	2–15 cmH_2O
Inspiratory flow	10–100 L/min
I:E ratio	4:1 to 1:4.5
Size (H × W × D)	50″ × 21″ × 16″ (128 × 53 × 41 cm)
Weight	47 kg (103 lb)
Power supply	100–240 VAC 50–60 Hz

*The Dräger Narkomed M is manufactured by Dräger **AG & Co,** Lübeck, Germany.
PEEP: positive end expiratory pressure
I:E: inspiration to expiration
CPAP: continuous positive airway pressure
VAC: volt alternating current

Figure 47-11. Narkomed gas flow and ventilation controls.
Product image used with permission from Dräger AG, Lübeck, Germany.

Manual or automatic ventilation can be selected using a selector situated on the circle absorber. Drive gas to the ventilator comes from the main gas supply being used. Oxygen or air can be selected as the drive gas via a selector switch on the right side of the machine. The anesthesia ventilator is a volume-preset, time-cycled, pressure-limited ventilator with electronic timing and pneumatic circuitry and controls for frequency, inspiratory-to-expiratory ratio, inspiratory flow rate, tidal volume, and inspiratory pressure control. The

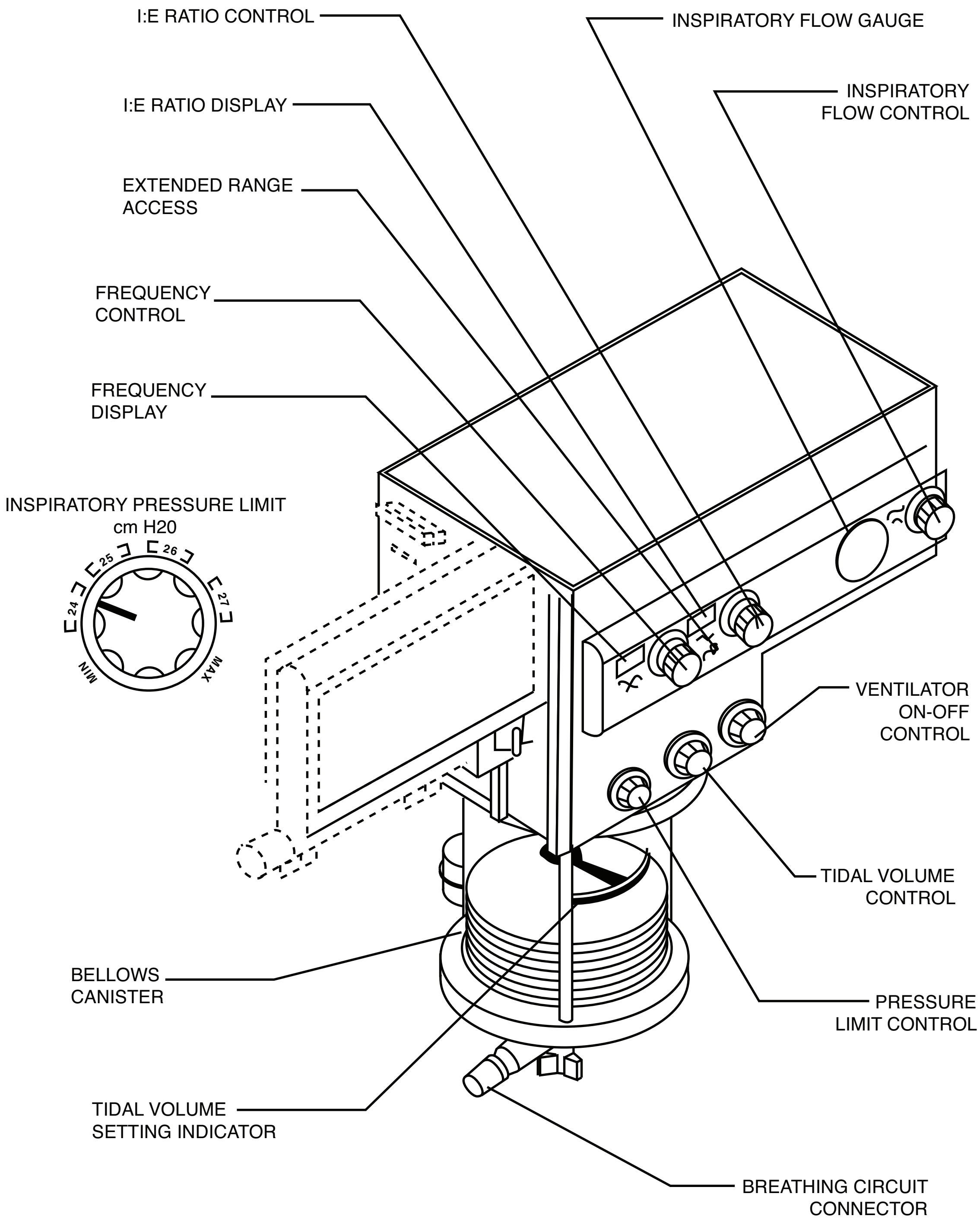

Figure 47-12. Layout of ventilation controls on the Narkomed M. I:E: inspiratory-to-expiratory. Product image used with permission from Dräger AG, Lübeck, Germany.

Narkomed M uses an ascending bellows; the effect of gravity on the bellows causes a positive end-expiratory pressure within the breathing system of about 2 cm H_2O. (Figure 47-12)

The machine is powered from an alternating current (AC) power source, but a backup battery can run the machine for at least 90 minutes. A three-pulse audible alarm will sound every 30 seconds and a caution message will be displayed to signal backup battery activation. When the battery nears depletion, "AC power fail" is displayed and indicates there is approximately 10 minutes of backup battery power remaining. If the battery is depleted and there is no AC power to the system, manual ventilation may be required. The machine cannot provide monitoring or alarm functions until AC power is restored.

OXYGEN SUPPLIES

The logistical burden of supplying oxygen cylinders to a deployed medical facility is significant. UK and US forces have approached these issues in a number of ways.

DeVilbiss Oxygen Concentrator

The DeVilbiss Oxygen Concentrator (DeVilbiss, Somerset, PA) is a compact, portable (16.8 kg) concentrator that uses the zeolite process to concentrate oxygen from room air (Figure 47-13). This particular model has a maximum output of 5 L/min and produces an oxygen concentration of up to 93% (± 3%; the higher the flow, the lower the concentration). It runs on central power (220–240 VAC). It is used by the UK DMS with the TSAA for low-flow oxygen requirements and to feed the intensive care unit (ICU) ventilator (see LTV 1000 Series ICU Ventilator, below). The controls are simple, consisting of a power switch and a flow meter. Warning devices include an orange light that indicates when oxygen output is less than 85%, an audible alert that sounds if oxygen drops below 75%, and a red light that appears if concentration falls below 60%.

Figure 47-13. DeVilbis oxygen concentrator.
Product image used with permission from DeVilbiss Healthcare Ltd, Tipton, West Midlands, United Kingdom.

Expeditionary Deployable Oxygen Concentrator System

The expeditionary deployable oxygen concentrator system (EDOCS) generator (Pacific Consolidates Industries, Riverside, CA) is a large, heavy piece of equipment (42 inches wide, 104 inches long, 67 inches tall, and approximately 1,500 kg) that can be used to fill oxygen cylinders as well as supply pipeline oxygen to a medical facility (Figure 47-14). Initial problems of dust and heat in recent operational environments have led to some design modifications as well as changes in operating procedures. The machine can be used at night to fill cylinders that supply the hospital pipeline. The EDOCS module generates oxygen using vacuum swing adsorption technology. The EDOCS-120B concentrator generates 120 L/min (7.2 m^3/h) at 85 psi. The oxygen (minimum 93% ± 3%) can be delivered directly from the concentrator to the hospital distribution system at 85 psi or supplied to the boost compressor, which compresses the gas to 2,250 psi to fill standard medical oxygen cylinders via a cylinder-filling manifold. A vacuum pump is included with the EDOCS to evacuate cylinders prior to filling. It is used at US Role 3 MTFs as well as at some combat air staging facility units.

Portable Oxygen Generator System

POGS, which was more recently developed, has been used by US forces in Afghanistan (Figure 47-15). Two versions are available. The POGS-10 is used in conjunction with the US Fabius Tiro M. The larger POGS-33 has been used with the Narkomed M but

Figure 47-14. Expeditionary deployable oxygen concentrator system oxygen generator.
Product image used with permission from Pacific Consolidates Industries, Riverside, CA.

Figure 47-15. Portable Oxygen Generator System (POGS-33).
Product image used with permission from On Site Gas Systems Inc, Newington, CT.

can also be used as a stand-alone system for filling oxygen cylinders. POGS-33 produces a total flow of 33 L/min of 93% oxygen or 30 L/min of medical-grade air. POGS consists of three components: (1) a feed air compressor, (2) an oxygen generator, and (3) a high-volume booster that enables the filling of oxygen cylinders. The feed air compressor is typically located outside the medical facility and should be in a clean, sheltered area. This compressed air is then transferred to the POGS. The oxygen generator functions as a molecular sieve and separates the oxygen from the nitrogen and water vapor. The high-volume booster is a compressor system that enables high-pressure oxygen storage. It produces a pressure of 2,250 psig at a flow of 30 to 120 scfh.

MONITORS

General Electric Healthcare Datex-Ohmeda S/5 Compact

The S/5 Compact (General Electric Healthcare, Chalfont St Giles, UK) is a typical modern anesthesia monitor with a color display (Figure 47-16). It has many similarities to the AS/3 model from which it is derived. It is transportable but, at 11 kg, it is heavier than some other portable monitors. However, the weight can be tolerated in favor of its other capabilities, including invasive pressures, volatile agent concentration, and spirometry. The color display is highly configurable, with up to eight wave forms and four digital fields. The left side of the screen can display a 30-minute trend or a flow volume loop with lung compliance measurements (Table 47-4). Trends can be displayed graphically or in tabular form and can be printed out. It can tolerate temperatures from 10ºC to 35ºC while operating. Recent military conflicts have shown that the S/5 Compact can be used in these temperatures without adverse event. This range of capabilities makes the S/5 Compact suitable for use as an anesthesia and critical care monitor.

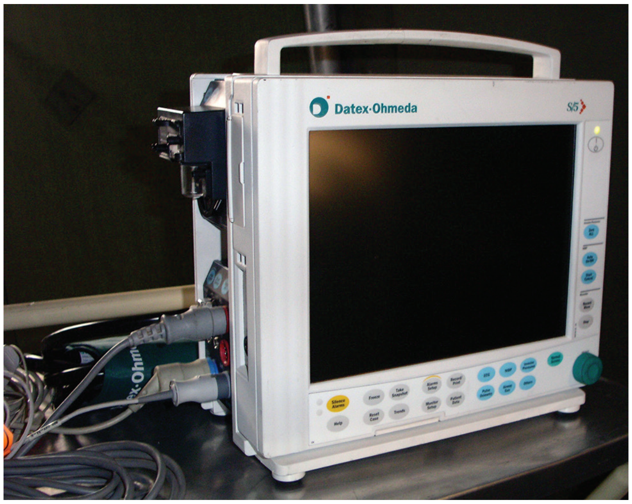

Figure 47-16. S/5 Compact monitor.
Product image used with permission from General Electric Healthcare, Chalfont St Giles, United Kingdom.

US Anesthesia Monitoring

US Role 2 and Role 3 facilities use a variety of monitors, including the Datex-Ohmeda AS/3, the Dräeger Vamos, and the Propaq. Because the AS/3 has an almost identical range of capabilities to the S/5, it will not be described further.

Dräeger Vamos

The Dräeger Vamos (Dräger AG & Co, Lübeck, Germany) anesthetic gas monitor is commonly supplied with the Narkomed M (See Figure 47-10) and is not normally seen as a stand-alone monitor. It is a compact module with a 5-inch, electroluminescent, amber display with various viewing angles. The device will monitor anesthetic agents, carbon dioxide, and nitrous oxide. There is graphic display of the carbon dioxide waveform and numeric displays of inspiratory and end-tidal concentrations of carbon dioxide, nitrous oxide, and volatile agent. The gas sensor samples at a flow of 200 mL/min, and the sampled gas can be returned to the anesthesia circuit.

Propaq

A number of Propaq (Welch Allyn, Beaverton, OR) models are used, but the variant with end-tidal carbon dioxide monitoring is preferred (see Figure 47-10).

TABLE 47-4

SPECIFICATIONS FOR THE S/5 COMPACT MONITOR*

Capabilities	Characteristics
Standard capabilities	ECG, NIBP, SaO_2
Advanced capabilities	Invasive pressure (2 channels), temperature (2 channels)
Gas monitoring	FiO_2, $EtCO_2$, Et volatile, spirometry, airway pressures, RR
Screen	12.1″ color display, 800 × 600, 8 waveforms, 4 digital fields
Power supply	100–240 VAC (50–60 Hz)
Battery back up	90 min, NiMH (60 min, NiCd)
Temp range stored	– 10ºC to + 50ºC
Temp range operational	10ºC to 35ºC

*The S/5 Compact monitor is manufactured by General Electric Healthcare, Chalfont St Giles, UK.
ECG: electrocardiogram
Et: end-tidal
$EtCO_2$: end-tidal carbon dioxide
FiO_2: fraction of inspired oxygen
NIBP: noninvasive blood pressure
NiCd: nickel cadmium
NiMH: nickel metal hydride
RR: respiratory rate
Temp: temperature
SaO_2: oxygen saturation
VAC: volt alternating current

In addition to electrocardiogram, noninvasive blood pressure, oxygen saturation, and two temperature channels, the Encore 206EL can monitor two invasive pressure channels as well as end-tidal carbon dioxide. The latter option requires the expansion module to be fitted below the main monitor. A range of alarms is available as well as trend data. The unit is powered from 12 to 28 volts direct current (VDC), which is compatible with vehicle and aircraft power supplies. The main unit comes in US (100–120 VAC) and European (200–240 VAC) options. There is a 3-hour battery life with all options, including end-tidal carbon dioxide, bringing the weight up to 6.1 kg. Although Propaq monitors are used at some lighter scale UK MTFs, they are not normally used as anesthetic monitors.

VENTILATORS

A limited range of ventilators is available to both forces to reduce logistics issues and the training burden for clinical and maintenance staff. For the UK DMS, the range available to field hospitals is limited to the

CompPAC 200 and the Vela (Carefusion, Yorba Linda, California). For ventilation in the emergency department and for intrahospital transfers, the CompPAC 200 is used (see The Triservice Anaesthetic Apparatus, above). The Vela is preferred for use in small children, even in the emergency department.

Vela

The Vela series comprises the Vela Comprehensive, Vela Plus, and Vela. The UK DMS has chosen the Comprehensive model (Figure 47-17), which is a fully specified, compact, mobile device. Features include a high-pressure oxygen inlet (40–85 psi) with blender, a low-pressure oxygen inlet (up to 0.5 psi, for example, from the DeVilbiss concentrator) with accumulator, and integrated monitoring and continuous display of delivered FiO_2, with high and low alarm settings. Turbine technology provides independence from compressors and wall air supplies. It can be used for pediatric or adult ventilation and has a broad range of operating modes, including volume control, pressure-regulated volume control, airway pressure release ventilation, biphasic pressure control, pressure support, noninvasive ventilation, SIMV, and continuous positive airway pressure (CPAP). There is apnea backup ventilation in SIMV and CPAP/pressure support ventilation. The ventilator tolerates a wide range of supply voltages (90–264 VAC at 47–65 Hz) and has a 6-hour internal battery. The 10.4-inch, active matrix, full-color touchscreen gives access to physiologic data and current ventilator status, including flow and volume loops and trends. The essential controls for the selected mode are displayed; inactive controls are not displayed until needed (Table 47-5).[12]

TABLE 47-5

SPECIFICATIONS FOR THE VELA VENTILATOR*

Capability	Characteristics
Tidal volume	50–2,000 mL
Rate	2–80 breaths/min
FiO_2	0.21–1.0
PEEP/CPAP	0–35 cmH_2O
PC/PS/spontaneous flow	To 140 L/min (180 L/min spont max)
PS	Off, 1–100 cmH_2O
Trigger sensitivity	Off, 1–20 L/min
PC	0–100 cmH_2O
Inspiratory time	0.3–10 s (100 L/min)
Size (H × W × D)	12″ × 13″ × 14.5″ (30.5 × 33 × 36.8 cm)
Weight	17.2 kg
Power supply	90–264 VAC, 47–65 Hz

*The Vela Ventilator is manufactured by Carefusion, Yorba Linda, CA.
CPAP: continuous positive airway pressure
FiO_2: fractioned inspired oxygen
min: minimum
max: maximum
PEEP: positive end expiratory pressure
PC: pressure control
PS: pressure support
spont: spontaneous
VAC: volt alternating current

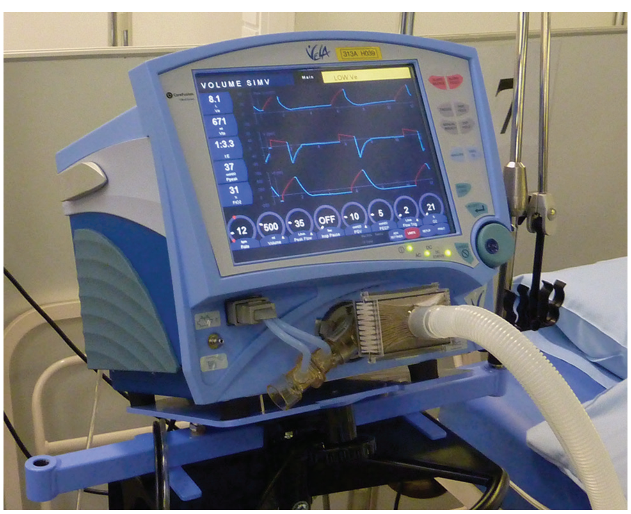

Figure 47-17. Vela ICU ventilator.
Product image used with permission from Carefusion, Yorba Linda, CA.

US Ventilators

Impact 754 Eagle Univent

The Univent (Impact Instrumentation Inc, West Caldwell, New Jersey) is a compact, versatile, portable flow generator (Figure 47-18). The ventilator has an internal battery that can be powered directly from any 11 to 15 VDC power supply. When operating on the internal compressor, the battery will last 3 hours; if external gas supplies are used, the battery can last 12 hours. There is a separate power supply unit that operates from international voltages and frequencies. Modes of ventilation include volume control, SIMV, pressure support, and CPAP (Table 47-6).

The ventilator has an internal compressor, but external oxygen and air cylinders can be attached. With an

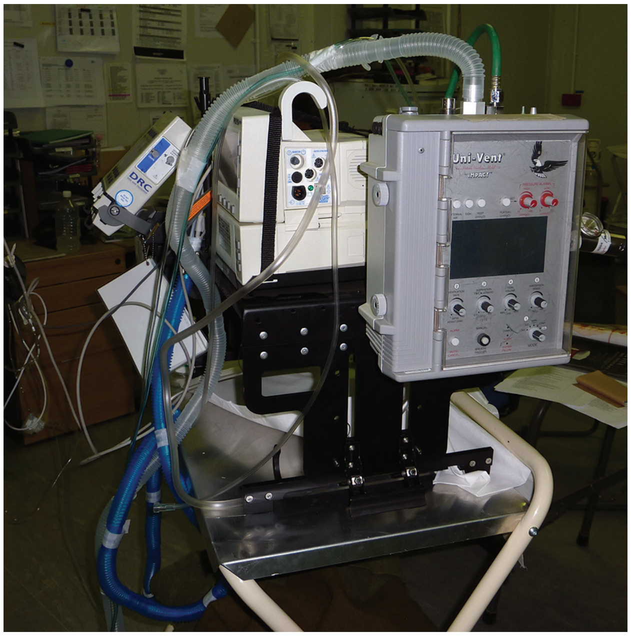

Figure 47-18. Impact 754 Eagle Univent.
Product image used with permission from Impact Instrumentation Inc, West Caldwell, NJ.

TABLE 47-6

SPECIFICATIONS FOR THE IMPACT 754 EAGLE UNIVENT*

Capability	Characteristic
Tidal volume	0–3,000 mL
Rate	1–150 breaths/min
FiO_2	0.21–1.0
PEEP/CPAP	1–20 cmH_2O
Flow rate	0–60 L/min
I:E ratio	1:1 to 1:599
Inspiratory time	0.1–3 s
Size (H × W × D)	11.5″× 8.87″ × 4.5″ (29.2 × 22.5 × 11.4 cm)
Weight	5.8 kg (13 lb)
Power supply	11–15 VDC, 100–240 VAC, 50–60 Hz

*The Impact 754 Eagle Univent is manufactured by Impact Instrumentation Inc, West Caldwell, NJ.
FiO_2: fraction of inspired oxygen
I:E: inspiration to expiration
VAC: volts alternating current
VDC: volts direct current

external oxygen source, the FiO_2 can be adjusted from 0.21 to 1.0(external sources must be 40 psi or more).

LTV 1000 Series ICU Ventilator

The LTV 1000 series (Carefusion, Yorba Linda, California) is used by US medical services as an ICU ventilator (Figure 47-19). UK Critical Care Air Support Teams also use it as a transport ICU ventilator, and it was used as a pediatric ventilator in ICUs prior to introduction of the Vela. With tidal volumes down to 50 mL, the device can be used for children weighing as little as 5 kg.

As with most modern ICU ventilators, there is a range of ventilation modes (volume control, pressure control, pressure support, spontaneous, SIMV, CPAP, noninvasive ventilation). The device runs from a similar power supply range as the Univent, and the main adaptor has international voltage capability (Table 47-7).

The ventilator will run on an internal battery for 45 minutes or an external battery pack (a 12 amp/h battery will last approximately 3 hours), as well as the main power supply unit. Using the same turbine technology as the Vela, the LTV 1000 will run from high- and low-pressure oxygen sources. When using a low-pressure oxygen source, the ventilator calculates delivered FiO_2 but does not measure it.

In hot climates, it is important to keep the air inlet filter damp and to check the side panel connections for the pressure- and volume-monitoring hoses, which have been known to loosen. It is an effective and versatile ventilator.

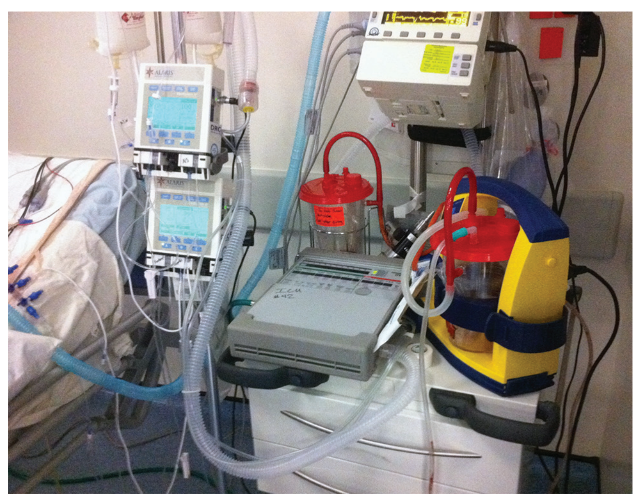

Figure 47-19. LTV 1000.
Product image used with permission from Carefusion, Yorba Linda, CA.

INTRAVENOUS INFUSION EQUIPMENT

Both the United Kingdom and the United States now use the same equipment for the aggressive volume resuscitation of casualties of conflict.

Level 1 H-1200 Fast Flow Fluid Warmer

The Level 1 H-1200 Fluid Warmer (Smiths Medical, Ashford, Kent) is an intravenous (IV) rapid infuser with fluid warming and two pressure chambers for fluids or blood products (Figure 47-20; Table 47-8). It has air detection and automatic clamping capability. The chambers pressurize the fluids, enabling rapid delivery. The infuser employs single-use, disposable administration sets that include a gas vent/filter assembly and heat exchanger to warm the IV fluids.

The installation, set-up, and replacement of Level 1 administration sets follows a four-step sequence that corresponds to numbered blocks on the device. The air detector/clamp monitors for the presence of air in the IV fluid path. When air is detected, the air detector/clamp closes off the patient line and triggers audible and visual alarms. This device has been used successfully by UK and US forces for some years, but it requires two operators per machine and occasionally must be swapped out to replace the disposable set. This means that more personnel may be involved than is sometimes ideal. The Level 1 Hotline HL-90 (Figure 47-21) is a more basic fluid warmer that is preferred to the H-1200 for pediatric massive transfusion. There is no air detection with this model (Table 47-9).

TABLE 47-7

SPECIFICATIONS FOR THE LTV 1000*

Capability	Characteristics
Tidal volume	50–2,000 mL
Rate	0–80 breaths/min
FiO_2	0.21–1.0
PEEP/CPAP	0–20 cmH_2O
PC/PS/spontaneous flow	To 160 L/min
PS	Off, 1–160 cmH_2O
Trigger sensitivity	Off, 1–9 L/min
PC	1–99 cmH_2O
Inspiratory time	0.33–9.9 s (100 L/min)
Size (H × W × D)	3” × 10” × 12” (8 × 25 × 30 cm)
Weight	6.1 kg
Power supply	11–15 VDC

*The LTV 1000 is manufactured by Carefusion, Yorba Linda, CA.
CPAP: continuous positive airway pressure
FiO_2: fraction of inspired oxygen
PC: pressure control
PEEP: peak end expiratory pressure
PS: pressure support
VDC: volts direct current

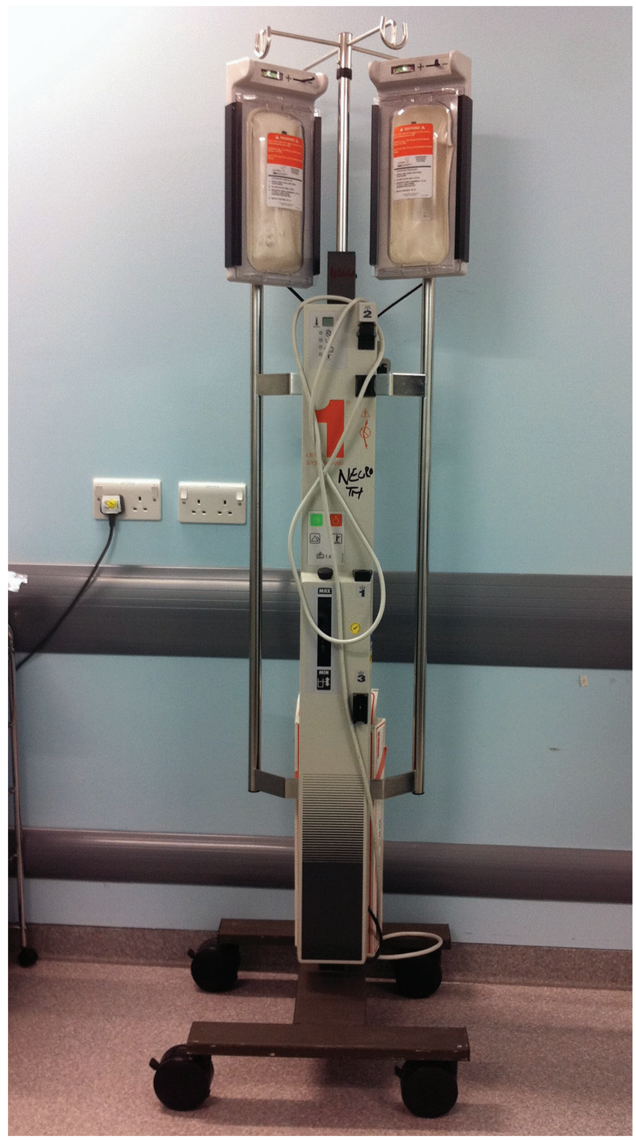

Figure 47-20. Level 1 H-1200.
Product image used with permission from Smiths Medical, Ashford, Kent, United Kingdom.

TABLE 47-8

LEVEL 1 HOTLINE H-1200* SPECIFICATIONS

Capability	Characteristic
Flow rate (10°C input temp)	Normothermic output up to 650 mL/min
Maximum flow rate (crystalloid)	1,400 mL/min
Reservoir capacity	1.4 L
Size (H × W × D)	67″ × 20″× 20″ (1.7 m × 51 cm × 51 cm)
Weight (dry)	63 pounds (28.5 kg)
Operating temp	10°C to 40°C
Central power supply	115 VAC 60 Hz, or 230 VAC 50 Hz

*The Level 1 Hotline H-1200 is manufactured by Smiths Medical, Ashford, Kent, UK.
temp: temperature
VAC: volts alternating current

Belmont Rapid Infuser FMS 2000

The Belmont Rapid Infuser FMS 2000 (Belmont Instrument Corp, Billerica, Massachusetts) is available to US medical services and, beginning in October 2011, it was also made available to deployed UK Role 3 hospitals (Figure 47-22). Rather than rely on a pressure-bag-style infusion capability, the FMS 2000 uses a roller pump. An electromagnetic induction heating system warms fluid from 4ºC to 37.5ºC in a single pass (< 45 seconds; Table 47-10).

Figure 47-21. Level 1 HL-90.
Product image used with permission from Smiths Medical, Ashford, Kent, United Kingdom.

There are two options for large-volume blood product administration: the standard administration set has a three-way spike system, but this upper section can be replaced by a 5-spike, 3-liter cardiotomy reservoir.

The 5-by-2.5-inch display walks the operator through the setup and priming process and shows flow rate, total volume infused, fluid temperature, and in-line pressure. Infusion pressure is continuously monitored and fluid infusion is stopped when the pressure is greater than 300 mm Hg or if there is a sudden pressure spike. Pressure monitoring will automatically restrict flow, so this should be expected where fluids are being infused through smaller vascular access devices (eg, intraosseous needles).[12] There is a recirculation facility that cycles fluid through the system at 200 mL/min. This permits fluids to mix in the reservoir, and it can also be used to warm fluid before disconnecting power for transport. There is an automatic purge of air after each 500 mL of infusion to keep the system clear of the air generated as fluids are warmed.

Unlike some other rapid infusers, the FMS 2000 has a battery backup that engages as AC power is disconnected. While on battery, the maximum infusion rate is

TABLE 47-9

LEVEL 1 HOTLINE HL-90* SPECIFICATIONS

Capability	Characteristics
Flow rate (10°C input temperature)	Normothermic output up to 3,500 mL/min
Maximum flow rate (crystalloid)	5,000 mL/min
Reservoir capacity	1.4 L
Size (H × W × D)	9.5″ × 8.3″ × 7″ (24.1 × 21 × 17.8 cm)
Weight (dry)	7.6 lb (3.5 kg)
Operating temperature	10°C to 45°C
Central power supply	100 VAC, 115 VAC, or 230 VAC 50/60 Hz

*The Level 1 Hotline HL-90 is manufactured by Smiths Medical, Ashford, Kent, UK.
VAC: volts alternating current

Figure 47-22. Belmont FMS200.
Product image used with permission from Genesy Medical Solutions, Ascot, United Kingdom.

restricted to 50 mL/min and there is no fluid warming. The battery provides at least 30 minutes of operation and has an 8-hour recharge time from flat.

Figure 47-23. Braun Perfusor.
Product image used with permission from B. Braun, Melsungen, Germany.

TABLE 47-10

BELMONT FMS 2000 SPECIFICATIONS*

Capability	Characteristics
Fluid pump	Peristaltic roller pump
Flow rate	2.5–750 mL/min
Bolus volume	100 mL to 500 mL (50 mL increments)†
Size (H × W × D)	13.5“ × 7.5“ × 12“
Weight	26 lb
Operating temperature	10°C to 32°C
Central power supply	115 VAC or 230 VAC

*The Belmont FMS 2000 is manufactured by Belmont Instrument Corp, Billerica, Massachusetts.
†Maximum bolus size for UK DMS is 250 mL.
VAC: volts alternating current

For the UK version, software changes have been implemented following cases of fluid volume overload using pressure-bag infusion pumps. UK Role 3 models have a maximum bolus volume of 250 mL.

Braun Perfusor Compact S

Used by the UK DMS, the Perfusor (B Braun, Melsungen, Germany) is a battery- and central-powered syringe driver (Figure 47-23; Table 47-11). In this

TABLE 47-11

SPECIFICATIONS FOR THE BRAUN PERFUSOR COMPACT S SYRINGE DRIVER*

Capability	Characteristics
Syringe selection	2/3, 5, 10, 20, 30, 50/60 mL
Delivery rate	0.01–200 mL/h (depends on syringe size)
Size (H ×W × D)	10 × 19 × 12 cm
Weight	1.5 kg
Power supply	Batteries (disposable/rechargeable), central power
Operating time using rechargeable pack	10 h at 10 mL/h
Operating time using alkaline batteries	80 h at 10 mL/h

*The Braun Perfusor Compact S Syringe Driver is manufactured by B. Braun, Melsungen, Germany.

case, the battery power is supplied by disposable AA cells, which have ubiquitous availability. Although a rechargeable battery pack is available, the pump lasts longer with disposable batteries.

The liquid-crystal display screen shows syringe type and size, delivery rate, infused volume, pressure alarm, and central power or battery operation. There is a three-bar battery indicator (ie, three bars means full power); batteries should be replaced when the display shows one bar. A maximum of three drivers can be stacked together and locked for transport. The Perfusor has the common alarm functions, including an occlusion alarm, an adjustable pressure limit, and an automatic bolus reduction following a pressure alarm. There are also alarms for 3 minutes before the syringe will empty and 30 minutes before the battery is discharged. The user interface is not intuitive, so it is important to become familiar with the pump before using it on patients; however, it appears to be reliable and is cleared for use on UK airframes.

SUMMARY

The sophistication and capabilities of modern medical equipment are continually advancing, and military medicine must continue to review its capabilities and update equipment where appropriate. In forward austere environments, compact, lightweight, and durable equipment is necessary for surgery and anesthesia; hence, compromises have been made in equipment to deliver a medical capability. At Role 3 MTFs, the equipment capability is increasingly at or above the standard seen in Western health services, which poses challenges for training, maintenance, and logistics.

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